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BY

DONALD HABER

FINAL REPORT FOR COOPERATIVE AGREEMENT WITH
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COST AND QUANTITIES MODEL FOR COMPOSITE ROADS

by

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Prepared for:

Intermountain Research Station
Forestry Science Laboratory
1221 South Main Street
Moscow, ID 83843

INTRODUCTION

Forest road designers have come under increasing pressure to lower construction costs without increasing undesirable environment impacts such as road prism erosion. To meet these pressures, road design standards have been changed. The composite road standard is such an effort to reduce costs. This standard can be compared with a higher standard road built to subgrade. This report outlines a method by which previous field data for roads built by hydraulic excavators can be used to estimate costs and design quantities for a composite designed road. The estimation model assumes a composite road will be constructed by a hydraulic excavator and that limited field data is available. In addition to estimates of cost and quantities, road surface area, cut area and fill area are estimated. From the exposed surface areas, sediment runoff can be predicted, given additional information concerning soil types, cut and fill erosion control measures and other site specific information as outlined by Burroughs and King[1] in their report on reduction of soil erosion on forest roads.

COST MODEL FOR COMPOSITE ROADS

Teasdale and Haber in 1985 developed a cost model for forest road construction based on field observations and data from 30 forest road construction projects involving 19 contractors on 10 National Forests. This cost model estimated costs for forest road construction built by hydraulic excavators. Although most roads observed in the 1985 study were of a higher standard than composite roads,

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[1]Draft manuscript on file at the Intermountain Research Station, Forestry Sciences Laboratory, 1221 S. Main St., Moscow, ID 83843

modification of the model to estimate composite road costs was made.

The Modified Cost model predicts production rates based on excavation quantities, clearing width, clearing class, grade, and the time of year construction occurs. Using the estimated production rate, total excavator machine hours can be predicted. Cost can then be determined by applying prevailing wage and equipment rental rates.

QUANTITIES MODEL AND EXAMPLES

The major input to the cost model is an estimate of excavation volume and clearing area. These design quantities, along with exposed surface can be calculated from the geometry of the road prism and other site factors. Two types of composite road geometry are shown in Figures 1 and 2. When machine dimensions, cut slope angle, fill slope angle, average side slope, road width and clearing width are known, the model determines the design quantities for either type of composite road.

Type I Cross Section

The cross section in Figure 1 approximates a pioneer road cross section where the backhoe excavates a level road the width of its tracks, and finishes the back slope. This type of road is usually found on self balanced sections on moderate side slopes. Refer to Figure 1 for the definition of angles and lengths in the following equations:

Cut area,
$$C_1 = \frac{x_1^2 \cdot \mathrm{Sin}(A)\ \mathrm{Sin}(S)}{2\ \mathrm{Sin}(A-S)} \qquad (1)$$

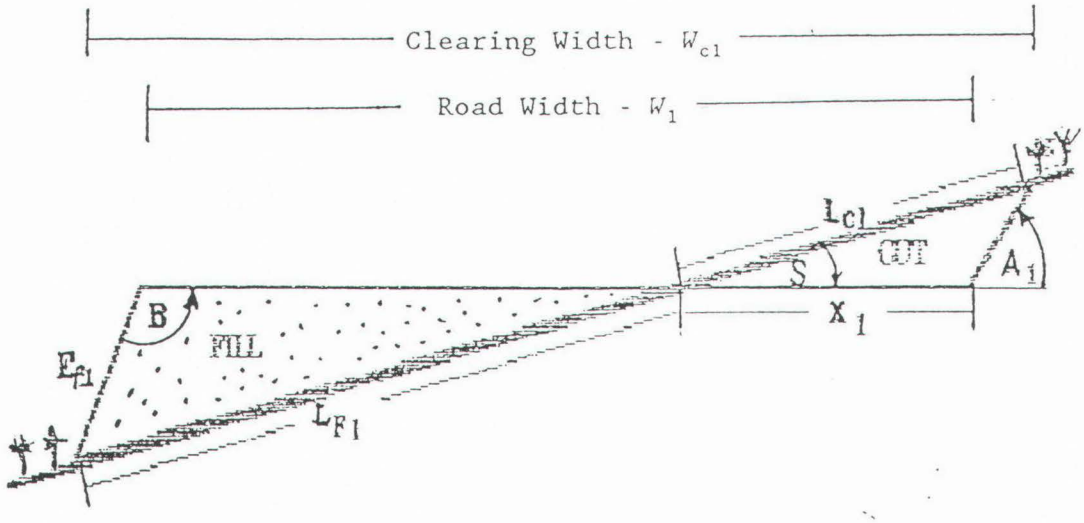

Figure 1. Type 1 Cross Section

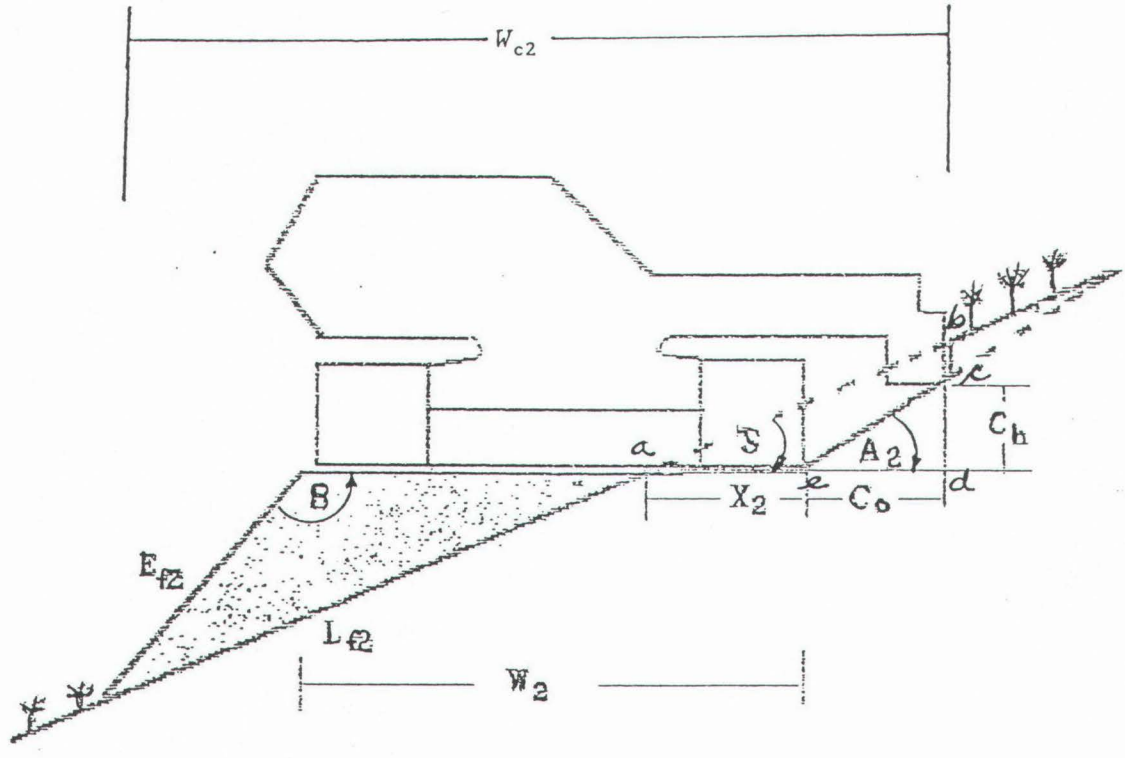

Figure 2. Type 2 Cross Section

Let $$R_1 = \frac{\text{Sin}(A)\ \text{Sin}(S)}{2 \cdot \text{Sin}\ (A-S)} \qquad (2)$$

So $$C_1 = R1 \cdot X_1^2 \qquad (3)$$

Fill area, $$F_1 = \frac{(W_1 - X_1)^2 \cdot \text{Sin}(B)\ \text{Sin}(S)}{2 \cdot \text{Sin}(180 - B - S)} \qquad (4)$$

Let $$Q = \frac{\text{Sin}(B)\ \text{Sin}(S)}{2 \cdot \text{Sin}(180 - B - S)} \qquad (5)$$

So $$F_1 = Q \cdot (W_1 - X_1)^2 \qquad (6)$$

In a self balanced section the fill area is equal to the cut area multiplied by a shrinkage factor or:

$$C_1 = F_1 \cdot (Sf) \qquad (7)$$

Substituting (3) and (6) into (7) and expanding the polynomial gives:

$$(Q \cdot Sf - R_1) \cdot X_1^2 - (2 \cdot W_1 \cdot Q \cdot Sf) \cdot X_1 + W_1^2 \cdot Q \cdot Sf = 0$$

Solving the quadratic gives:

$$X_1 = \frac{2 \cdot W_1 \cdot Q \cdot Sf - [(2 \cdot W_1 \cdot Q \cdot Sf)^2 - 4 \cdot (Q \cdot Sf - R_1)\ (W_1^2 \cdot Q \cdot Sf)]^{1/2}}{2 \cdot (Q \cdot Sf - R_1)}$$

Where X_1 is the cutbench width and the negative root of the quadratic gives the appropriate solution.

After solving for X_1, it can be substituted back into (3) to calculate the cut area. Then the excavation volume per linear foot of road can be calculated by:

$$PXCV1 = R1 \cdot X_1^2 / 27 \qquad (8)$$

Where X_1 is in feet and PXCV1 is in cu yds per ft.

Minimum clearing width W_{c1} can also be calculated from the geometry if X_1 is known. From the Law of Sines:

$$\frac{Sin(A - S)}{X_1} = \frac{Sin(A)}{Lc_1}$$

Or $$Lc_1 = \frac{X_1 Sin(A)}{Sin(A - S)}$$

Also $$\frac{Sin(180 - B - S)}{W_1 - X_1} = \frac{Sin(B)}{L_{f1}}$$

Or $$Lf_1 = \frac{(W_1 - X_1)\ Sin(B)}{Sin(180 - B - S)}$$

Minimum clearing width W_{c1} is then calculated by:

$$Wc_1 = Lc_1 \cdot Cos(S) + L_{f1} \cdot Cos(S)$$

$$= \frac{X_1\ Sin(A)\ Cos(S)}{Sin(A - S)} + \frac{(W_1 - X_1)\ Sin(B)\ Cos(S)}{Sin(180 - B - S)}$$

Similarly, exposed road surface (E_{s1}) can be calculated as:

$$E_{s1} = W_1 + E_{c1} + E_{f1}$$

where $$Ec1 = \frac{X_1\ Sin(S)}{Sin(A - S)} \quad \text{and} \quad Ef_1 = \frac{(W_1 - X_1)\ Sin(S)}{Sin(180 - B - S)}$$

So $$E_{s1} = W_1 + \frac{X_1 \sin(S)}{\sin(A - S)} + \frac{(W_1 - X_1)\sin(S)}{\sin(180 - B - S)}$$

Type 2 Cross Section

The pioneer road cross section in Figure 2 approximates a cross section where the backhoe excavates enough for a level set with room to swing the counterweight past the cut bank. This type of pioneer road is usually found on cut and fill sections and in steeper terrain. The calculations require more machine dimensions than the first method. Figure 2 defines the geometry of the cross section and figure 3 is used to help define the cut area C_2.

To calculate cut area, C_2, first calculate the area abcd

$$\text{Area abcd} = \frac{(X_2 + C_o) \cdot (X_2 + C_o) \cdot \tan(S)}{2}$$

$$\text{Area decd} = \frac{C_o \cdot C_o \cdot \tan(A_2)}{2}$$

Area abed = Area abcd - Area decd

$$C_2 = \frac{\tan(S)}{2} \cdot (X_2+C_o)^2 - \frac{\tan(A_2)}{2} \cdot C_o^2 \qquad (9)$$

and $$F_2 = Q \cdot (W_2-X_2)^2 \qquad (10)$$

also $$C_2 = F_2 \cdot S_f \qquad (11)$$

then $$F_2 \cdot S_f = S_f \cdot Q(W_2-X_2)^2 = \frac{\tan(S)}{2} \cdot (X_2+C_o)^2 - \frac{\tan(A_2) \cdot C_o^2}{2}$$

Collecting Terms to form a quadratic in X_2:

$$\left(\frac{\tan(s)}{2}-Q\cdot S_f\right)\cdot X_2^2 + \left(C_o\cdot\tan(S)+Q\cdot S_f\cdot 2W_2\right)X_2 + C_o^2\left(\frac{\tan(S)}{2}-\frac{\tan(A_2)}{2}\right) - Q\cdot S_f\cdot W_2^2=0$$

Solving the quadratic for X_2:

$$=\frac{-(C_o\cdot\tan(S)+Q\cdot S_f\cdot 2W_2)-[(C_0\cdot\tan(S)+Q\cdot S_f\cdot ZW_2)^2-4(\frac{\tan(S)}{}-Q\cdot S_f)\cdot(C_o^2(\tan(S)-\tan(A_2))-Q\cdot S_f 2W_2)]^{1/2}}{2\left(\frac{\tan(S)}{2} - Q\cdot S_f\right)}$$

Finally using the negative root of the quadratic for X_2, one can calculate the excavation volume per linear foot of road by:

$$PXCV_2 = Q\cdot S_f(W_2-X_2)^2/27 \qquad (12)$$

and the cut area by:

$$C_2 = Q\cdot(W_2-X_2)^2\cdot S_f \qquad (13)$$

Minimum clearing width can be calculated with Lf the same as for the Type I cross section:

$$Wc_2 = Lf\cdot Cos(S) + X_2 + Co$$

$$W_{c2} = \frac{(W_2 - X_2)\ Sin(B)\ Cos(S)}{Sin(180 - B - S)} + X_2 + Co$$

Exposed surface, ES_2, can be calculated with the same formulation as in the Type I cross section:

$$Es_2 = \frac{(W_2 - X_2)\ Sin(S)}{Sin(180 - B - S)} + W_2 + (X_2+C_o)\tan(S)-C_h+C_o/Cos(A_2)$$

Example Calculation for Type I Cross Section

Problem:

Given the following data, estimate pioneering excavation for three road segments based on a Type 1 cross section.

Begin Station - End Station	0-23	23-56	56-79.2
Avg Side Slope %	45	36	57
Avg Clearing Width (ft)	40	37	53
Clearing Class*	3	3	4
Avg Favorable Grade	6	5	8
Percent Length in Favorable Grade	39	15	100
Avg Adverse Grade	-2	-6	0
Percent Length in Adverse Grade	69	85	0

*1 = X-Light, 2 = Light, 3 = Medium, 4 = Heavy, 5 = X Heavy

Road width = 14 ft

Cut Slope is 1:1 (A_1 = 45 degrees)

Fill Slope is 1.5 : 1 (B = 146 degrees)

Shrink Factor, Sf = 1.2 (Fill/Cut Area = 1.2)

SOLUTION:

Sta 0 - 23

$S = \text{Arctan}(45/100) = 24.2$

$R_1 = \text{Sin}(45)\ \text{Sin}(24.2) / 2\ \text{Sin}(45 - 24.2)$

$= 0.2899/0.7102 = 0.4081$

$Q = \text{Sin}(146.3)\ \text{Sin}(24.2) / 2\ \text{sin}(180 - 146.3 - 24.23)$

$= .6918$

$Q \cdot Sf - R_1 = .6918\ (1.2) - .4081 = .4221$

$2 \cdot W_1 \cdot Q \cdot Sf = 2(14) \cdot (.6918) \cdot (1.2) = 23.2445$

$$X = \frac{23.2445 - [(23.2445)^2 - 4 \cdot (.4221)(14)^2 \cdot (.6981)(1.2)]^{0.5}}{2(.4221)}$$

$= 8.32$ ft

$PXCV_1 = 0.4081 \cdot (8.32)^2 / 27 = 1.049$ cu yd / ft

****

To calculate minimum clearing width (horizontal distance from cut stake to fill stake):

$$Wc = \frac{8.32 \cdot \text{Sin}(45)\text{Cos}(24.23)}{\text{Sin}(45 - 24.23)} + \frac{(14 - 8.32) \cdot \text{Sin}(146.3)\text{Cos}(24.23)}{\text{Sin}(180 - 146.3 - 24.23)} = 32.6 \text{ ft.}$$

To calculate exposed surface in the cross section:

$$Sx = 14 + \frac{8.32 \text{ Sin}(24.23)}{\text{Sin}(45 - 24.23)} + \frac{(14 - 8.32) \text{ Sin}(24.23)}{\text{Sin}(180 - 146.3 - 24.2)}$$

$= 37.8$ sq ft / ft

Example Calculation for Type 2 Cross Section

Problem:

Using the data from the previous example and the additional machine dimensions given below, calculate pioneering excavation based on a Type 2 cross section.

Track Width, $W_2 = 11.3$ ft

Counterweight overhang, Co = 5.2 ft

Counterweight height, Ch = 3.8 ft

SOLUTION:

$A = \text{Arctan}(Ch / Co) = \text{Arctan}(3.8 / 5.2)$

$= 36.2$ degrees

$S = \text{Arctan}(45/100) = 24.2$ degrees

$R_2 = \text{Sin}(36.2)\ \text{Sin}(24.2) / 2\ \text{Sin}(36.2 - 24.2)$

$= 0.5822$

$Q = \text{Sin}(146.3)\ \text{Sin}(24.2) / 2\ \text{Sin}(180 - 146.3 - 24.2)$

$= .6918$

$N = \text{Sin}^2(24.2) / \text{Sin}^2(36.2 - 24.2) = 3.887$

$P = 2\ (5.2)\ \text{Sin}(24.2) / \text{Cos}(36.2)\ \text{Sin}(36.2 - 24.2)$

$= 25.410$

$M = 5.2^2 / \text{Cos}^2(36.2 = 41.5243$

$K = \text{Sin}(36.2)\ \text{Sin}(90 - 36.2) / 2\ \text{Sin}(90 + 24.2)$

$= 0.0920$

$2\ W_2 \cdot Q \cdot Sf + P \cdot K = 2\ (11.3)(.6918)(1.2) + 25.410\ (.0920)$

$= 21.163$

$Q \cdot Sf - R_2 + N \cdot K = .6918(1.2) - .5882 + 3.887(.0920)$

$= .5996$

$W_2 \cdot Q \cdot Sf + M \cdot K = 11.3^2\ (.6918)(1.2) + 41.5243\ (.0920)$

$= 109.823$

$$X_2 = \frac{21.163 - [21.163 - 4\ (.5996)(109.823)^5]}{2(.5996)}$$

$= 6.32$

$PXCV_2 = .6918\ (1.2)\ (11.3 - 6.32)^2 / 27$

$= 0.76$ cu yds / ft

****

To calculate minimum clearing width (width of cut fill section):

$$W_{c2} = \frac{(11.3 - 6.32)\ \text{Sin}(146.3)\ \text{Cos}(24.23)}{\text{Sin}(180 - 146 - 24.2)} + 6.32 + 5.2$$

$$= 26.8 \text{ ft}$$

To calculate exposed surface:

$$ES_2 = (11.3 - 6.32)\ \text{Sin}(24.23) / \text{Sin}(180 - 146.3 - 24.23) + 11.3 +$$

$$(6.32 + 5.2)\ \text{Tan}(24.23) - 5.2\ \text{Tan}(36.28) + 5.2 / \text{Cos}(36.2)$$

$$= 31.1 \text{ sq ft / ft}$$

The above solutions should provide a reasonable first approximation of backhoe pioneering excavation in common excavation on side slopes from 10 to 60 percent. On flat ground the backhoe may excavate more than indicated by the equations due to stump excavation and stripping. Steep ground may require full bench excavation and stripping in place of the self balanced excavation assumed in the equations. In addition, some restrictions on the use of the above equations are imposed because of mathematical formulation. They are:

1. The fill slope must be steeper than the side slope, in order for the fill triangle to close, otherwise it would be impossible to calculate fill area.
2. If the cut slope angle and the fill slope angle are equal, and if the shrinkage factor is 1, then the quadratic solution simplifies to a direct solution of X, and X will be equal to one half the road width (track width).
3. In the equations for the Type 2 cross section the side slope must be steeper than the angle A calculated from machine dimensions. For a Caterpillar 235 the minimum side slope is:

$$\text{Minimum Side Slope} = \frac{\text{Counterweight Height (100)}}{\text{X + Counterweight Overhang}}$$

For a Caterpillar 235 trial and error solution indicates that the minimum side slope is about 35 percent. For side slopes less than this value, the Type 1 cross section with road width equal to track width is more appropriate.

COST MODEL EXAMPLE

Once the quantity model develops the basic design quantities as illustrated in the two previous examples, the modified cost model can be utilized. This model uses a regression type equation of the form:

Rate = 145.225 - 16.721 * EXCAVATION QUANTITY (CU YD/FT) - 1.096 * CLEARING WIDTH (FT) - 16.026 * CLEARING CLASS (1-5) - 3.0 * ADVERSE GRADE[2] (5%) + 6.734 MONTH (1-12).

This regression model predicts the backhoe production rate in ft/hr.

Example Type I Cross Section

Using the same data from road section as in the previous examples, the quantity model calculated the following estimates:

Excavation Quantity/ft	1.026	cu yd/ft
Clearing Width	32.7 ft	

If the construction month is given as June (6) and the clearing class is 3, with a centerline grade of -5%, the equation predicts:

Rate = 145.225 - 16.721 * (1.026) - 1.096*(32.7

- 16.026*(3) - 3*(5) + 6.734*(6)

---

[2] An adverse grade is defined in this context as an uphill pull by the excavator coming back pushing excavated material after first clearing ahead. It is analogus to a logging truck pulling an uphill grade going out after being loaded. An adverse grade would be input as a positive value.

Rate = 69.56 ft/hr

COMPUTER PROGRAM SOLUTION

A computer program written in BASICA (IBM Basic) was developed to facilitate the cost and quantity estimations. The program is based on the analysis as outlined in the previous sections. In addition to determining cost and quantity information, the user is prompted to enter the necessary information. Results of the program are output on a printer. Estimates of quantities and rates for each section of composite road are printed and displayed along with a summary for the entire road up to and including the immediate section.

Examples of computer solutions to the examples are illustrated on the following pages. The source code used for this program is given in the appendix.

The program can be run on any PC compatible with IBM BASICA.

FUTURE WORK

The model proposed in this report estimates the exposed area of the road design prism. The exposed area is further separated into that contained in road surface, cut and fill slopes. As noted previously, Burroughs and King in their draft paper, present information on estimation of erosion reduction due to erosion control techniques applied to a forest road. Development of the relationships between exposed road surfaces, soil characteristics, rainfall, and sediment yield on forest roads is an on-going project with USFS, Intermountain Research Station, Engineering Technology Project, Moscow, ID.

By combining information on the appropriate exposed area as calculated by this model, erosion control, and a model of road erosion and sediment transport, an estimate of sediment production from the road prism can be determined.

As soon as new or updated information becomes available, modification of the present model to include capability to estimate sediment production from composite roads will be made.

APPENDIX

BASICA program for the Cost and Quantity Model

REFERENCES

Teasdale, G. and Haber, D. F., Hydraulic Backhoe Pioneering and Subgrading in Low Volume Forest Road Construction, Report, U.S. Forest Service, Region IV, Missoula, MT, 1986

Burroughs, E. R. and King, J. G., Reduction of Soil Erosion on Forest Roads, Draft Report 1988, Intermountain Research Station, Forestry Science Laboratory, Moscow, ID.

```
2 LPRINT CHR$(27)"l"CHR$(10)
4 LPRINT CHR$(27)"N"CHR$(6)
10 REM Tracked backhoe pioneering and subgrading in the construction of low
20 REM volume forest roads in northern Idaho and western Montana
30 REM Program calculates backhoe pioneering excavation and production rates
40 REM Gregg N. Teasdale and Donald f. Haber
50 REM Dept. of Civil Engr
60 REM University of Idaho
70 REM August 1985
80 CLS: KEY OFF
90 PRINT "*************************************************************************
100 PRINT
110 PRINT "            Backhoe Pioneering And Subgrading Production"
120 PRINT
130 PRINT "*************************************************************************
140 PRINT
150 PRINT "Select Pioneering Cross section"
160 PRINT
170 PRINT "     A:  Excavation just enough for free backhoe swing and self-bala
ced"
180 PRINT
190 PRINT "     B:  Excavation pulled down from cut stake and self-balanced"
200 PRINT
210 INPUT "     A or B  "; EX$
220 PRINT
230 INPUT "Do You Want Backhoe Production Calculated?  (Y or N) "; PREN$
240 IF PREN$ = "Y" OR PREN$ = "y" THEN GOTO 250 ELSE GOTO 270
250 PRINT
260 INPUT "When Will Pioneering Occur?  ( Month, 1 - 12)"; MO
270 PRINT
280  STO = 0: OLDCA = 0: XTOT = 0: OLDSA = 0: SATOT = 0: PHOURTOT = 0: CLRTOT =
0: SATOT1 = 0: SATOT2 = 0: SATOT3 = 0:
290 INPUT "Road Begins at Station  =  "; STO
300 PRINT
310 IF EX$ = "A" OR EX$ = "a" THEN CX$ = "A"
320 IF CX$ = "A" THEN GOSUB 1150 ELSE GOSUB 2350
330 GOSUB 360   ' Road Total and Printing Subroutine
340 IF CX$ = "A" THEN GOSUB 1440 ELSE GOSUB 2430
350 GOTO 330  ' Cycles Back to Road Total and Printing Subroutine
360 ROLENG =(STN - STO) * 100  ' Convert stations to length in feet
370 XVOL = CAREA * ROLENG
380 XTOT = XTOT + XVOL
390 SAREA = XSURF*ROLENG
391 IF EX$ = "A" THEN 392 ELSE 400
392 L2= L2 + L4 + L5
400 SAREA1 = L1 * ROLENG
410 SAREA2 = L2 * ROLENG
420 SAREA3 = L3 * ROLENG
430 SATOT = SATOT + SAREA / 43560!
440 SATOT1= SATOT1+ SAREA1/ 43560!
450 SATOT2= SATOT2+ SAREA2/ 43560!
460 SATOT3= SATOT3+ SAREA3/ 43560!
470 IF PREN$ = "Y" OR PREN$ = "y" THEN GOSUB 870
480 IF PREN$ = "Y" OR PREN$ = "y" THEN CLRWTH = ACLRWTH
490 CLRAR = CLRWTH * ROLENG
500 CLRTOT = CLRAR / 43560! + CLRTOT
510 PRINT
520 CUTA = CAREA * 27
530 FMT2$ = "Cut Area in Section  =                  ####.##    sq ft"
540 PRINT USING FMT2$; CUTA
545 LPRINT USING FMT2$; CUTA
546 LPRINT
547 LPRINT
550 OLDCA = CAREA
560 OLDSA = XSURF
570 STO = STN
```

```
580 PRINT
581 LPRINT
590 FMT1$ = "Cut Volume In Section  =            #######.##    cu yd"
600 PRINT USING FMT1$; XVOL
601 LPRINT USING FMT1$; XVOL
610 PRINT
612 LPRINT
620 REM "Exposed Surface  =  "; XSURF; "ft / ft"
630 FMT3$ = "Total Cut Volume =                  #######.##    cu yd"
640 PRINT USING FMT3$; XTOT
641 LPRINT USING FMT3$; XTOT
650 PRINT
651 LPRINT
652 LPRINT
660 FMT4$ = "Total Exposed Surface  =              #####.##    acres"
661 LPRINT
670 PRINT USING FMT4$; SATOT
671 LPRINT USING FMT4$; SATOT
672 LPRINT
680 FMT7$ = "  Total cut exposed surface =         #####.##    acres"
690 PRINT USING FMT7$; SATOT2
691 LPRINT USING FMT7$; SATOT2
692 LPRINT
700 FMT8$ = "  Total road exposed surface =        #####.##    acres"
710 PRINT USING FMT8$; SATOT1
711 LPRINT USING FMT8$; SATOT1
712 LPRINT
720 FMT9$ = "  Total fill exposed surface =        #####.##    acres"
730 PRINT USING FMT9$; SATOT3
731 LPRINT USING FMT9$; SATOT3
740 PRINT
741 LPRINT
742 LPRINT
743 LPRINT
750 FMT5$ = "Clearing Area In Section  =            #######    sq ft"
760 PRINT USING FMT5$; CLRAR
765 LPRINT USING FMT5$; CLRAR
770 PRINT
771 LPRINT
780 FMT6$ = "Total Clearing Area  =                #####.##    acres"
790 PRINT USING FMT6$; CLRTOT
791 LPRINT USING FMT6$; CLRTOT
800 PRINT
801 LPRINT
810 INPUT ">>>>>>>>>  Another Section ?   (Y or N) "; ONEMORE$
820 IF ONEMORE$ = "N" OR ONEMORE$ = "n" THEN GOTO 3730
830 CLS
840 PRINT "******** Enter New Section Data,  Section Begins At Station :  ";
    STO; "****"
850 PRINT
860 RETURN
870 REM Backhoe Production Subroutine
880 PRINT
890 INPUT "Actual Clearing Width  (hit enter to use above value)"; ACLRWTH
900 IF ACLRWTH = 0 THEN ACLRWTH = CLRWTH
910 PRINT
920 INPUT "Clearing Class   (1 - 5)"; CLRCLS
930 PRINT
940 INPUT "Road Grade, % "; GRADE
950 PRINT
960 IF GRADE < 0 THEN ADV = 100 * ABS(GRADE) ELSE ADV = 0
970 PIONRATE = 145.225 - 16.721 * XAV - 1.096 * ACLRWTH - 16.026 * CLRCLS
              - .03 * ADV + 6.734 * MO
980 CLS
990 PRINT "***********  ROAD AND SECTION PRODUCTION SUMMARY  ****************"
991 LPRINT "***********  ROAD AND SECTION PRODUCTION SUMMARY  ****************"
```

```
1000 PRINT
1001 LPRINT
1010 PRINT "                    EXCAVATION METHOD :  "; CX$
1011 LPRINT "                     EXCAVATION METHOD :  "; CX$
1020 PRINT
1021 LPRINT
1030 PRINT "Section :"; STO; "-"; STN; "   Cutside Slope = "; SC; "%"; "   Fill
side slope = "; SS; "%"; "   Grade = "; GRADE; "%"; "   Fill Angle = "; FIX(FLA
G); " Deg"
1031 LPRINT "Section :"; STO; "-"; STN; "   Cutside Slope = "; SC; "%"; "   Fil
 side slope = "; SS; "%"
1032 LPRINT
1033 LPRINT "Grade = "; GRADE; "%"; "   Fill Angle = "; FIX(FLANG); " Deg"
1040 PRINT
1041 LPRINT
1050 PRINT "CLEARING WIDTH = "; FIX(ACLRWTH); " FT";            "   CLEARING CL
SS = "; CLRCLS
1051 LPRINT  "Clearing Width = "; FIX(ACLRWTH); " ft";            "   Clearing
lass = "; CLRCLS
1060 PRINT "-------------------------------------------------------------------"
1061 LPRINT
1070 FMT7$ = "Backhoe Pioneering Rate  =             ####.#     ft / hr"
1080 PRINT USING FMT7$; PIONRATE
1081 LPRINT USING FMT7$; PIONRATE
1090 PRINT
1091 LPRINT
1100 PHOURS = ROLENG / PIONRATE
1110 PHOURTOT = PHOURTOT + PHOURS
1120 FMT8$ = "Total Pioneering Time  =              #####.#     hours
1130 PRINT USING FMT8$; PHOURTOT
1131 LPRINT USING FMT8$; PHOURTOT
1132 LPRINT
1140 RETURN
1150 REM Begin 'A' Excavation Subroutine
1160 CLS
1170 PRINT "********************  EXCAVATION METHOD A  ************************"
1180 PRINT
1190 PRINT "Select Machine or Enter Machine Dimensions Under 'Other'"
1200 PRINT
1210 PRINT "    Cat 225    Cat 235    Hitachi UH122    Other "
1220 PRINT
1230 INPUT "     Machine =  "; MACHINE$
1240 PRINT
1250 IF MACHINE$ = "Cat 235" OR MACHINE$ = "CAT 235" OR MACHINE$ = "cat 235" OR
MACHINE$ = "CAT235" OR MACHINE$ = "cat235" OR MACHINE$ = "Cat235" OR MACHINE$ =
"Cat235" GOTO 2160
1260 IF MACHINE$ = "CAT 225" OR MACHINE$ = "Cat 225" OR MACHINE$ = "CAT225" OR
ACHINE$ = "Cat225" OR MACHINE$ = "cat 225" OR MACHINE$ = "cat225" GOTO 2220
1270 IF MACHINE$ = "Hit uh122" OR MACHINE$ = "hit uh122" OR MACHINE$ = "Hitachi
UH122" OR MACHINE$ = "UH122" OR MACHINE$ = "HitachiUH122" OR MACHINE$ = "HITACH
 UH122" OR MACHINE$ = "uh122" OR MACHINE$ = "hitachi uh122" GOTO 2280
1280 IF MACHINE$ = "Other" OR MACHINE$ = "other" THEN GOTO 2050 ELSE GOTO 2050
1290 REM Return here after obtaining machine dimensions
1300 PRINT "Enter Road And Soil Specifications"
1310 PRINT
1320 INPUT "     Shrink Factor "; SF
1340 PRINT
1350 INPUT "     Fill Slope  (hoz / vert)   Hoz = "; HOZ
1360 INPUT "                               Vert = "; VERT
1370 PI = 3.141593
1380 FLANG1 = 180 - ATN(VERT / HOZ) * 180 / PI
1390 FSANG1 = FLANG1 * PI/180  'in radians
1400 PRINT
1410 REM Return here for additional sections
1420 PRINT "Enter Section Data :  Section Begins at Station :  "; STO
1430 PRINT
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```
1440 INPUT "     Side Slope, % "; SS
1450 FLANG = FLANG1
1460 FSANG = FSANG1
1470 IF SS = 999 GOTO 3730
1480 IF SS < 60 THEN GOTO 1530
1490 PRINT
1500 INPUT "Full Bench Section  ?   (Y or N)  "; FBS$
1510 IF FBS$ = "Y" OR FBS$ = "y" THEN GOSUB 3510 ELSE GOTO 1530
1520 GOTO 2030
1530 SSR = ATN(SS/100)     'in radians
1540 IF SSR >= (PI - FSANG) THEN FSANG = PI * .75: FLANG = 135 ELSE GOTO 1550
1550 PRINT
1560 INPUT "End of Section Station "; STN
1570 PRINT
1580 MINSS = CBHT / (.5 * TRKWTH + OVRHNG) * 100
1590 IF SS < MINSS THEN AC$ = "Y": GOTO 1600 ELSE GOTO 1630
1600 DELTR = FSANG: ALPHR = ATN(CBHT / OVRHNG)
1610 GOSUB 3080
1620 IF AC$ = "Y" THEN GOTO 1900
1630 PI = 3.141593
1640 ALPHA = ATN(CBHT / OVRHNG)    'in radians
1650 Q = SIN(SSR) * SIN(FSANG) /2 /(SIN(PI -FSANG -SSR)) * SF
1660 R = SIN(SSR) * SIN(PI - ALPHA) / 2 / SIN(ALPHA - SSR)
1670 N = SIN(SSR) ^ 2 / SIN(ALPHA - SSR) ^ 2
1680 P = OVRHNG * 2 * SIN(SSR) / COS(ALPHA) / SIN(ALPHA - SSR)
1690 M = OVRHNG ^ 2 / COS(ALPHA) ^2
1700 MM = SIN(ALPHA - SSR) * SIN(PI/2 - ALPHA) / 2 / SIN(PI/2 + SSR)
1710 A = Q - R + MM * N
1720 B = -(2 * TRKWTH * Q + MM * P)
1730 C = TRKWTH ^2 * Q + M * MM
1740 CUTWTH = (-B - SQR(B^2 - 4*A*C)) / (2*A)    ' quadratic eqn, neg root
1750 CAREA = (TRKWTH - CUTWTH) ^ 2 * Q / 27
1760 REM Calculation of Exposed Surface
1770 AS = CUTWTH * SIN(PI - ALPHA) / SIN(ALPHA - SSR)
1780 L4 =  (CUTWTH + OVRHNG) * TAN(SSR)
1790 L5 = - OVRHNG * TAN(ALPHA)
1800 L1 = TRKWTH
1810 L2 = OVRHNG / COS(ALPHA)
1820 L3 = (TRKWTH - CUTWTH) * SIN(SSR) / SIN(PI - SSR - FSANG)
1830 XSURF = L1 + L2 + L3 + L4 + L5
1840 LL = (TRKWTH - CUTWTH) * COS(SSR) * SIN(FSANG) / SIN(PI - FSANG - SSR)
1850 RR = CUTWTH * SIN(PI - PI/4) * COS(SSR) / SIN(PI/4 - SSR)
1860 CLRWTH = LL + RR
1870 IF (LL - (TRKWTH - CUTWTH) > 1.5 * TRKWTH) THEN GOTO 1880 ELSE GOTO 1900
1880 FSANG = PI * .75: FLANG = 135
1890 GOTO 1630
1900 CLS
1910 PRINT "**************EXCAVATION METHOD A :  SECTION  "; STO; "-"; STN; "**
********"
1915 LPRINT "**************EXCAVATION METHOD A :  SECTION  "; STO; "-"; STN; "*
*********"
1920 PRINT
1925 LPRINT
1930 IF PREN$ = "Y" OR PREN$ = "y" THEN GOTO 1980
1940 PRINT "Machine =  "; MACHINE$; "     Side Slope =  "; SS; " %"; "     Fill
Angle =  "; FIX(FLANG); "  Deg"
1945 LPRINT "Machine =  "; MACHINE$; "     Side Slope =  "; SS; " %"; "     Fil
 Angle =  "; FIX(FLANG); "  Deg"
1950 PRINT
1955 LPRINT
1960 PRINT "---------------------  Road and Section Summary  -----------------"
1965 LPRINT "---------------------  Road and Section Summary  -----------------
1970 PRINT
1975 LPRINT
1980 FMT9$ = "Cut Bench Width  =                        ##.#     ft"
1990 PRINT USING FMT9$; CUTWTH
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1995 LPRINT USING FMT9$; CUTWTH
2000 PRINT
2010 FMT10$ = "Minimum Clearing Width  =                ###.#      ft"
2020 PRINT USING FMT10$; CLRWTH
2025 LPRINT USING FMT10$; CLRWTH
2030 RETURN
2040 REM End of 'A' Excavation Subroutine
2050 REM Other Machine Subroutine For Machine Dimensions
2060 PRINT "Enter Backhoe Dimensions"
2070 PRINT
2080 INPUT "     Backhoe Track Width"; TRKWTH
2090 PRINT
2100 INPUT "     Counterweight Overhang"; OVRHNG
2110 PRINT
2120 INPUT "     Counterbalance Height"; CBHT
2130 PRINT
2140 GOTO 1290
2150 REM End of 'Other Machine' Dimension Subroutine
2160 REM Cat 235 Dimension Subroutine
2170 TRKWTH = 11.33
2180 OVRHNG = 5.17
2190 CBHT = 3.75
2200 GOTO 1290
2210 REM End of Cat 235 Subroutine
2220 REM Cat 225 Dimensions Subroutine
2230 TRKWTH = 9.83
2240 OVRHNG = 4.34
2250 CBHT = 3.42
2260 GOTO 1290
2270 REM End of Cat 225 Subroutine
2280 REM Hitachi UH122 Dimension Subroutine
2290 TRKWTH = 9.83
2300 OVRHNG = 5.09
2310 CBHT = 3.75
2320 GOTO 1290
2330 REM End of Hitachi UH122 Subroutine
2340 REM End of 'A' Excavation Subroutine Including Machines
2350 REM Begin 'B' Excavation Subroutine
2360 CLS
2370 PRINT "********************  EXCAVATION METHOD B  ************************"
2380 PRINT
2390 INPUT "Are the cut and fill slope slopes constant thru-out the road length
 ? (Y or N)";CU$
2400 PRINT
2410 INPUT "Are the road width and shrink factor constant thru-out the the road
length ? (Y or N)";L$
2420 GOTO 2460
2430 IF CU$="N" OR CU$="n" THEN 2450 ELSE 2440
2440 IF L$="N" OR L$="n" THEN 2850 ELSE 2910
2450 IF L$="Y" OR L$="y" THEN 2770 ELSE 2630
2460 CX$ = "B"
2470 PRINT "Enter Road Specifications"
2480 PRINT
2490 INPUT "     Road Width (Track Width)"; TRKWTH
2500 PRINT
2510 INPUT "     Cut Slope  (Hoz / Vert)    Hoz = "; HOZC
2520 INPUT "                               Vert = "; VERTC
2530 PRINT
2540 INPUT "     Shrink Factor"; SF
2560 PRINT
2570 INPUT "     Fill Slope  (hoz / vert)   hoz = "; HOZF
2580 INPUT "                               vert = "; VERTF
2590 PRINT
2592 INPUT "   Left Minimum Clearing Width = ";LC
2594 PRINT
2596 INPUT "   Right Minimum Clearing Width = ";RC
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2598 PRINT
2600 REM
2610 PRINT "Enter Section Data :  Section Begins at Station :  "; STO
2620 GOTO 2910
2630 PRINT "Input the section properties"
2640 PRINT
2650 INPUT "     Road width =";TRKWTH
2660 PRINT
2670 INPUT "     Cut slope (horz/vert) horz=";HOZC
2680 INPUT "                           vert = "; VERTC
2690 PRINT
2700 INPUT "     Shrink factor =";SF
2720 PRINT
2730 INPUT "     Fill slope (horz/vert) horz=";HOZF
2740 INPUT "                           vert=";VERTF
2750 PRINT
2760 GOTO 2910
2770 PRINT "Input the section properties"
2780 PRINT
2790 INPUT "     Cut slope (horz/vert) horz = "; HOZC
2800 INPUT "                           vert = "; VERTC
2810 INPUT "     fill slope (horz/vert) horz=";HOZF
2820 INPUT "                           vert=";VERTF
2830 PRINT
2840 GOTO 2910
2850 PRINT "Input the section properties"
2860 PRINT
2870 INPUT "     Road width =";TRKWTH
2880 PRINT
2890 INPUT "     Shrink factor =";SF
2900 PRINT
2910 INPUT "Cut Side Slope,  %"; SC   'return here to skip redundant data
2915 INPUT "Fill Side Slope, %"; SS   'return here to skip redundant data
2920 PI = 3.141593
2930 DELTA1 = 180 - ATN(VERTF /HOZF) * 180 / PI
2940 ALPHA  = ATN(VERTC/HOZC) * 180 / PI
2950 DELTA = DELTA1
2960 IF SC = 999 GOTO 3730
2965 IF SS = 999 GOTO 3730
2970 ALPHR = ALPHA * PI / 180
2980 IF SS < 60 THEN GOTO 3030
2990 PRINT
3000 INPUT "Full Bench Section  ?   (Y or N)  "; FBS$
3010 IF FBS$ = "Y" OR FBS$ = "y" THEN GOSUB 3510 ELSE GOTO 3030
3020 GOTO 3490
3030 DELTR = DELTA * PI / 180
3040 SSR = ATN(SS/100)
3045 SSC = ATN(SC/100)
3050 IF SSR >= (PI - DELTR) THEN DELTR = PI * .75: DELTA = 135 ELSE GOTO 3060
3060 PRINT
3070 INPUT "     End of section station"; STN
3080 IF SC = 0 OR SS = 0 THEN GOTO 3320   'ALSO COME HERE FROM 'A' if ss < ssmi
3090 IF 180-ALPHA = DELTA AND SF = 1 THEN GOTO 3100 ELSE GOTO 3130
3100 CAREA = (TRKWTH/2) ^ 2 * SIN(PI - ALPHR) * SIN(SSC) / 2 / SIN(ALPHR - SSC)
27
3110 CUTWTH = TRKWTH / 2
3120 GOTO 3200
3130 QFS = SIN(DELTR) * SIN(SSR) / 2 / SIN(PI - DELTR - SSR) * SF
3140 R = SIN(PI - ALPHR) * SIN(SSC) / 2 / SIN(ALPHR - SSC)
3150 A = QFS - R
3160 B = -(2 * TRKWTH * QFS)
3170 C = TRKWTH^2*QFS
3171 IF B^2 - 4*A*C >= 0 THEN 3180
3172 PRINT
3173 CLS
3174 PRINT "THE CUTSLOPE SPECIFIED IS LESS THEN THE GROUND SLOPE"
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3176 PRINT "INPUT A NEW CUTSLOPE OR USE A FULL BENCH SECTION"
3177 PRINT
3178 GOTO 170
3180 CUTWTH = (-B - SQR(B ^2 - 4 * A * C)) / (2 * A)
3190 CAREA = CUTWTH ^ 2 * R / 27
3200 REM Calculation of exposed surface
3210 L1 = TRKWTH
3220 L2 = SIN(SSR) * CUTWTH / SIN(ALPHR - SSR)
3230 L3 = SIN(SSC) * (TRKWTH - CUTWTH) / SIN(PI - DELTR - SSC)
3240 XSURF = L1 + L2 + L3
3250 REM Calculation of Clearing Width
3260 LL1 = (TRKWTH - CUTWTH) * COS(SSR) * SIN(DELTR) / SIN(PI - DELTR - SSR)
3261 LL = LL1
3262 IF LL < LC THEN LL = LC
3270 RR = CUTWTH * SIN(PI - ALPHR) * COS(SSC) / SIN(ALPHR - SSC)
3272 IF RR < RC THEN RR = RC
3280 CLRWTH = LL + RR
3290 IF (SS/100 >= VERTF/HOZF) THEN GOTO 3300 ELSE GOTO 3340
3292 IF LL >= 35! THEN GOTO 3294 ELSE GOTO 3340
3294 PRINT "THE CLEARING AND THE FILL IS GREATER THEN THE SWING, IT WILL"
3296 PRINT "BE VERY TIME CONSUMING TO MAKE TWO PASSES"
3298 INPUT "DO YOU WANT TO CHANGE YOUR FILL ANGLE OR CLEARING LIMITS (Y OR N)";
L$
3299 IF CL$ = "y" OR "Y" GOTO 2730 ELSE 3340
3300 PRINT "FILL SLOPE IS LESS THAN THE GROUND SLOPE, DO YOU WANT A FULL"
3305 INPUT "BENCH SECTION (Y OR N)?  ";FB$
3310 IF FBS$ = "Y" OR FBS$ = "y" THEN GOSUB 3510 ELSE GOTO 3315
3315 PRINT "CHANGE THE FILL SLOPE TO A DIFFERENT (STEEPER) VALUE "
3317 GOTO 2730
3320 REM Come here if side slope is zero
3330 CAREA = 0: CUTWTH = 0: CLRWTH = TRKWTH: XSURF = TRKWTH
3340 IF AC$ = "Y" THEN RETURN
3350 CLS
3360 PRINT "**************EXCAVATION METHOD B :  SECTION  "; STO; "-"; STN; "**
********"
3370 PRINT
3375 LPRINT
3380 IF PREN$ = "Y" OR PREN$ = "y" THEN GOTO 3430
3390 PRINT "Road Width = "; TRKWTH; " ft"; "   Fill Angle = "; FIX(DELTA); "Deg

3395 LPRINT "Road Width = "; TRKWTH; " ft"; "    Fill Angle = "; FIX(DELTA); "D
g"
3396 LPRINT "Cut Side Slope = ";SC; "%  ";"Fill Side Slope ="; SS; "%"
3400 PRINT
3401 LPRINT
3405 LPRINT
3410 PRINT "--------------------  Road and Section Summary  ------------------"
3411 LPRINT "--------------------  Road and Section Summary  ------------------
3420 PRINT
3421 LPRINT
3430 FMT11$ = "Cut Bench Width  =                          ##.#     ft"
3440 PRINT USING FMT11$; CUTWTH
3450 PRINT
3460 FMT12$ = "Minimum Clearing Width  =                 ###.#     ft"
3470 PRINT USING FMT12$; CLRWTH
3480 FLANG = DELTA
3490 RETURN
3500 REM End of 'B' Excavation Subroutine
3510 REM Begin full bench subroutine
3520 PI = 3.141593
3530 IF CX$ = "A" THEN ALPH = PI/4 ELSE ALPH = ALPHR
3540 SSR = ATN(SS/100)
3550 PRINT
3560 INPUT "Station "; STN
3570 PRINT
3580 CAREA = TRKWTH ^2 * SIN(PI - ALPH) * SIN(SSR) / 2 / SIN(ALPH - SSR) /27
3590 CUTWTH = TRKWTH
3600 CLRWTH = TRKWTH * SIN(PI - ALPH) * COS(SSR) / SIN(ALPH - SSR)
3610 XSURF = TRKWTH + TRKWTH * SIN(SSR) / SIN(ALPH - SSR)
3620 CLS
3630 PRINT "**********  Full Bench Excavation :  Station  "; STO; "-"; STN; "**
****"
3640 PRINT
3650 PRINT
3660 PRINT "--------------------  Road and Section Summary  -----------------"
3670 PRINT
3680 PRINT
3690 FMT13$ = "Minimum Clearing Width  =                 ###.#     ft"
3700 PRINT USING FMT13$; CLRWTH
3710 RETURN
3720 REM End of full bench subroutine
3730 PRINT "STOP"
3740 END
```